A review of **radiometers** used for Fiducial Reference Measurements used for Satellite Radiometric Validation

“Do we know enough about our instruments to complete an uncertainty estimate?”

Presented by Kevin Ruddick (RBINS) at FRM4SOC Final Workshop, 2018-10-04 with support from FRM4SOC partners and instrument manufacturers (Biospherical, CIMEL, IMO, Satlantic/Seabird, TRIOS, WaterInsight)
What is known about existing radiometers? (for making a uncertainty budget)

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<th>Parameter</th>
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How well do you know your instruments?
Can you fill this Table with references?
... and estimate an uncertainty budget for your instrument?
Instruments studied

• Biospherical/C-OPS
• CIMEL/SeaPRISM
• IMO/DALEC
• Satlantic OCR500
• Satlantic HyperOCR
• TRIOS/RAMSES
• WaterInsight/WISP
Spectral Response function and wavelength calibration

- Spectral response function usually defined via:
  - Central Wavelengths and FWHM (per detector/filter)
  - OR full spectral response function
- Symmetrical and ~ Gaussian (spectrometers) or square (filters)
- Often specified by component suppliers
  - e.g. Zeiss MMS1 spectrometer or filter manufacturers
- Sometimes checked by instrument suppliers
  - e.g. WISP OceanOptics HG-1
Spectral straylight - spectrometers

[Zeiss MMS1 spectrometer diffraction grating – see Youtube]

Imperfections (e.g. secondary reflections) can cause photons with wavelength $\lambda_1$ to reach detector of wavelength $\lambda_2$ : (spectral) straylight
Spectral straylight - spectrometer

- e.g. Test results available for Zeiss MMS1 and OceanOptics JAZ spectrometers

Straylight Distribution Function matrix for a TRIOS/RAMSES radiance sensor – see [Talone et al, 2016]
Spectral out of band response – filter wheel radiometers

Polychromatic Light

Filter wheel for sequential measures

Monochromatic Light

Photodetector

[Source: Technoteam LMK Color]
Spectral out of band response – filter wheel radiometers

• Component specifications, e.g. spectral response function of filter [CIMEL Electronique]

• Can be validated for whole instrument with tunable laser
Radiometric calibration

• Laboratory absolute calibration investigated in FRM4SOC laboratory intercomparison (LCE-1 and LCE-2) activities

• Temporal variability of radiometric sensitivity can be followed for some instruments with portable calibration devices

TRIOS/FieldCAL

OceanOptics LS-1 (WISP)
Example calibration time series
[RBINS: LABcals+TRIOS/FieldCALS]

(but beware that these calibration devices have their own uncertainties: thermal sensitivity, positioning sensitivity, etc.)
(also recommend intercalibration checks)

HIGHROC intercomparison, NIVA (Oslo), 2015

IAFE/RBINS intercomparison, Buenos Aires, 2017
Immersion factor for underwater measurements

• In-water calibration different from in-air e.g. [Zibordi and Voss, 2014]:
  – Irradiance, E: reduced transmittance of water-diffuser interface (each sensor individually!)
  – Radiance, L: decrease in solid angle FOV, increase in transmittance of optical window (less inter-sensor variability)
Radiometric noise and Dark current

• If no light enters sensor there is still:
  – Slowly-varying signal (“dark current”)
  – Fast-varying signal (“noise”) and digitisation

• BOTH may depend on temperature and integration time

• Various strategies for “dark current” removal:
  – Internal shutters or opaque filter in wheel, OR
  – (spectrometer) “dark pixels” not illuminated
  – THEN remove this signal (with same integration time) from measurement

• “Noise” should be kept negligible in uncertainty budget
Radiometric linearity

• Spectrometers and photodetectors may have non-linear response with increasing signal, especially near saturation
  – E.g. (Hamamatsu) "as long as the output is within 95% of the saturation charge, the linearity error can be held to a small value by using an external circuit in the current-integration readout mode". Severe non-linearity problems occur above 95% of the saturation limit, which is avoided in by reducing integration time when necessary.

• Difficult to find any validation test information

• Some new results during FRM4SOC project
Thermal stability

• Electronic components (photodetectors, ADC, etc.) often sensitivity to temperature:
  – A) Dark Current
  – B) Responsivity

• Thermal regulation of instrument is possible but very expensive (OSPREY)

• Thermal characterisation of instruments allows correction to reduce uncertainties
  – Time lag with ambient temperature?
  – Internal temperature reading?
  – [JRC, Tartu, Australia/IMO tests]
Thermal sensitivity - examples

e.g. Hamamatsu S1336 photodetector (CIMEL/SeaPRISM)

Tests on WISP-3 spectrometer [Ghezhegn et al. 2015]
Angular response - radiance

- Generally specified as FWHM Field of View, but could be checked...

[CIMEL Electronique]
Angular response - irradiance

• Depends on diffuser head geometry and material
• Each unit is different ...

6 TRIOS RAMSES-ACC irradiance sensors
Normalised at 20° In air

Polarisation sensitivity

• Mirrors have significant polarisation sensitivity ... and the sea surface is highly polarised at 40°
• Diffusers, fibre optics decrease polarisation sensitivity
• Polarisers may also be used to block air-water ("skyglint") reflection

SIMBADA
sunphotometer/radiometer
(R. Frouin)
What is known about existing radiometers? (for making a uncertainty budget)

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Characterisation of radiometers

• Good response/information from:
  – Biospherical/C-OPS
  – CIMEL/SeaPRISM
  – IMO/DALEC
  – Satlantic/Seabird-HyperOCR+OCR500
  – TRIOS/RAMSES (inc. JRC and TARTU tests)
  – WaterInsight/WISP

• BUT some characteristics may be unit-specific ... and very time-consuming to characterise

• Draft report discussed and approved by manufacturers at Sept2017 workshop, publicly available from www.frm4soc.org

• Update planned for Dec2018 - any new tests/doc?